RESEARCH HIGHLIGHTS

August 2002

Technical Series 02-103

MOLDY HOUSES: WHY THEY ARE AND WHY WE CARE & ADDITIONAL ANALYSIS OF WALLACEBURG DATA: THE WALLACEBURG HEALTH AND HOUSING STUDIES

Introduction

About 30 questionnaire studies from around the world have shown a consistently strong correlation between occupant-reported respiratory disease symptoms and reported moisture and mold problems in houses. The Canadian questionnaire study by Health Canada, looking at 15,000 houses in 30 communities in five geographical regions of Canada, was one of the largest of those studies and showed some of the strongest correlations. Questionnaire studies are prone to biases in reporting, however, and are best followed up by well-designed field studies that compare actual exposure with measured health outcomes. CMHC worked with Dr. Robert Dales of Health Canada and Dr. David Miller, then with Agriculture Canada and now with Carleton University, to design a field study that would measure exposure to a number of indoor air pollutants, the health of early school age children, and the conditions and performance of their houses. Several projects were funded over a number of years, first to develop the necessary protocols, then to measure exposure in a Phase I study, and finally to measure house condition and several health indicators in the Phase II study reported here. A number of papers have been written on those studies and are identified at the end of this Research Highlight. They expand on some correlations discussed here.

This program of projects was carried out in Wallaceburg Ontario, a town northeast of Lake St. Clair between Sarnia and Windsor. This town has moderate weather and was chosen to be representative of the average of the weather regimes for the cross-country survey. The Phase I houses were chosen from those occupied by students attending the earlier grades of elementary school. The Phase II houses were selected from the Phase I set, according to the degree of mold exposure measured in Phase I.

Research Program

In the 1993/94 Phase I of the field testing program, biological exposure concentrations were measured in 402 houses, with good and complete measurements obtained in 367 of those houses. A questionnaire was used to determine reported mold and respiratory symptoms. Even with a different mix of houses, the distribution of responses was remarkably similar to those measured in two previous questionnaires in this town. The Phase I field samples included:

1. Short-term air samples, indoors and out;
2. Air dust samples from the living room and the index child's bedroom;
3. Swabs from visibly-moldy areas; and
4. Dust from the index child's bedding.

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The Index Child was the one selected to have their bedroom and health effects identified for more specific study. Some index children shared bedrooms, while others had their own room.

These phase I samples were analyzed for viable mold spores and ergosterol (a component of mold), for cat and dust mite antigen and for bacterial endotoxin. This analysis produced a huge set of biological exposure data. It was analyzed to determine houses that exposed the index child to either very large and relatively small amounts of biological materials. The Phase I reported health problems correlated primarily with mold exposure. Sixty Phase II houses were chosen from those sets, 40 in the high exposure category and 20 in the lower exposure range. Because of a late cancellation, only 39 high exposure houses were tested. The range of exposures to dust mite and cat antigen, as well as bacterial endotoxin, was about three decimal orders of magnitude; with the range of mold measures somewhat smaller but still very large.

Measuring the moisture and air quality performance of houses, as well as the exposure and health outcomes of the occupants, is an evolving area of both science and engineering. To ensure that the research program was successful, several techniques were further developed before the main Phase II house performance testing study was carried out. A team of housing consultants, Appin and Associates, Sheltair Scientific Ltd. and Scanada Consultants Ltd., assembled many sampling and investigation protocols and prepared draft survey forms. The tests included:

1. A protocol for predicting the air exchange rate of houses, AIM2, which is based on measured air tightness and weather data, acquired from its authors Walker and Wilson at the University of Alberta.
2. A local condensation prediction model, acquired from TenWolde of the US Forest Product Laboratory.
3. Sheltair assembled a composite condensation prediction model using these two components.
4. The CGSB B149.10 M86 Air Tightness test was modified to incorporate new procedures proposed for incorporation in an update. Flues and intentional openings that would be open during normal operation were to be left unblocked. Leaving these openings unsealed would help improve the prediction of actual air exchange in the houses, an important requirement for the study. Air tightness data obtained this way would not correlate well with previous data, however.
5. A cough recording system of hardware and software was developed by Health Canada, for overnight records of actual coughing by the index child.

Several techniques were used unmodified:

1. Tracer gas testing was performed to the requirements of ASTM E 741-83-90.
2. Susceptibility of combustion appliances to spillage was tested according to CAN/CGSB 51.71-94.
3. Temperature, Relative Humidity and Carbon Dioxide readings in the index child's bedroom were recorded at 10 minute intervals for five to seven days, using ACR 203s instruments.
4. VOC sampling was performed using 3M passive dosimeters, exposed for a week in the living room and analyzed by GC/FID.
5. Health data, including nasal secretions and a blood sample, were taken by a nurse at the time she administered the health questionnaire.
6. The children and parents were taught how to use the TruZone Peak Flow Meter and took readings morning and night for a week. They also logged the occupancy of the bedroom.

The field work was carried out during the late winter period of 1995, with most data obtained during February and March. Even after careful cleaning and processing of the available measurements, some data was not available in a few houses, for instance air tightness in three houses. In most cases, however, data was relatively complete. Removal of 'bad' data points allowed use of air exchange rate test results from 58 of the full set of 59 houses.

Analysis

The data, including selected Phase I exposure data, was entered into a Microsoft ACCESS relational database. Many of the subsequent correlations were performed using subsets of this data in EXCEL. For measures that showed both high ranges of results and many zero readings, ranks were assigned to the data (i.e. 1 through 59 if there were 59 data points). Both these sets of data were analyzed, and correlations compared. The statistical significance of all correlations was determined, so that both the size of the effect and the statistical merit of that correlation were available.

Statistical analysis of selected health data was run on SPSS and BMDP, by Corrine Dulberg, Ph.D.

Moisture Source Strength calculations were determined for the houses on which air tightness data was available. Using a mass balance calculation, on the moisture coming in with the outdoor air minus that leaving with the indoor air, a difference in moisture flow can be calculated. Estimates were also made of the occupant-related moisture generation rates, using historical CMHC references.

Condensation potential was calculated using a modification of the tools developed before the study. These programs were 'adjusted' so that they predicted window condensation for cases where it had been observed. When the program predicted condensation on a window it would also predict condensation within insulated structures, if air leakage paths were available, so this condensation condition should be interpreted as an indication of possible interstitial condensation.

Results

These studies debunked a number of preconceptions by demonstrating that:

1. Air leaky houses did not have less mold than tight ones.
2. The group of houses with high contamination were leakier than the group of houses with low contamination, although there was a fair spread of leakiness in both sets.
3. Tighter houses had lower air exchange rates, but did not have higher relative humidities, higher levels of condensation nor higher levels of biological contamination.
4. Leaky houses had higher predicted and measured air exchange rates and lower relative humidities, but higher (not the expected lower) measures of biological contamination.
5. Air leaky houses did not guarantee good ventilation in bedrooms, so that high Carbon Dioxide (CO_2) concentrations occurred in leaky houses as well as tight ones. Some of the worst were very leaky houses.
6. High measured relative humidity, indicated as either spot measurements taken at the time of the house inspection or the long-term average in the index child's bedroom, did not correlate well with biological contamination.
7. Visible mold growth did not correlate well with other measures of mold or with other biological contamination measurements in air or dust.
8. VOC measurements did not correlate well with any health effect measured for the child. The relatively small range of VOC totals and the small size of the study could explain that result.
9. Occupant moisture generation behaviour was not a good predictor of measured moisture source rates. Problems with the house itself were often the source of moisture, including wet basements and crawl spaces and other such problems supposedly covered by building codes.
10. The contaminated house set was smaller and had more occupants, so they had higher occupant densities, but these characteristics did not correlate well with measured moisture source strengths.
11. Higher air exchange rates were predictors of higher bacterial endotoxin, higher mold ergosterol and higher colony forming units, **not** the lower levels that most would assume.

Positive correlations were observed for the following:

1. Calculated moisture source strengths correlated well with dust mite antigen and viable mold spore counts (as Colony Forming Units or CFU).
2. Local moisture sources and problems were a better predictor of visible mold growth than relative humidity.
3. Condensation potential (using inputs of moisture source strength, ventilation rate and indoor-outdoor temperature differences) correlated with some of the blood lymphocyte measures, especially CD45O3CT.
4. Several mold growth factors correlated with blood lymphocyte changes, even after controlling for factors such as the age of the child, presence of pets, dust mite antigen levels, the child having a cold during the testing, CO_2 concentrations and VOC concentrations and presence of a humidifier in the child's room. This is remarkable in such a small study, since correcting for so many confounding factors reduces the statistical power of any study, and this is a small one by conventional standards.
5. The presence of wood burning appliances correlated with several measured factors: ergosterol; dust mite antigen; and one of the immune system changes in the child's blood.
6. Houses with unusual characteristics, such as cold cellars, aviaries, basement insulation with no vapour retarder, gas stoves or wall furnaces used for heating, HRVs installed but not even connected to the electrical system were all in the highly-contaminated house set.

Other observations include:

1. Mold growth from condensation on windows was common, even in houses with low measured mold in air and dust.
2. Many of the sources of moisture problems were not related to condensation. Some of the problems were: bathroom splashing and wetting; basement water leaks from the soil, through walls or floor; continually-wet refrigerator defrost or drain pans, etc.
3. Many of the observed moisture and mold growth problems are related to soil contact problems, in crawl spaces, basement walls and floor slabs. Surfaces that separate the soil from the building must be designed and built to prevent wicking and leaking of water, as well as infiltration of damp soil gases.
4. A disproportionate number of the highly-contaminated houses were built in the 1970s while a disproportionate number of the low-exposure houses were built since 1986.
5. The peak carbon dioxide (CO_2) concentrations in some bedrooms was very high, exceeding the 3,500 ppm maximum recommended by Health Canada. In several bedrooms the effective air exchange rate was only a few litres per second per child (L/s/child). In many of the bedrooms, use of the CO_2 concentrations predicted air exchange rates that are under the rate of 5 L/s per person recommended by ASHRAE.
6. While the AIM2 program predicted the average air exchange rate during the one hour test period quite well, it was a poor predictor of the measured rate in many individual houses. Many assumptions have to be made about the house and its interaction with the local environment, and these assumptions are not all well-founded in fact. The models themselves may be inadequate in some areas.
7. Ventilation by itself will not prevent problems. It is source rates that dominate the existence of problems, since ventilation varies slightly compared to the large variations in source rates.

Implications

This study presents a number of implications for the housing industry and the codes/standards committees and officials.

1. In many moisture-troubled houses it is apparently not the occupants, but the houses themselves, that are responsible for the large moisture source strengths that seem to drive biological contamination, including dust mites and mold growth. (However, there are many moisture-troubled houses where the moisture sources were obviously from occupant activities.) Most houses cannot process large amounts of moisture without getting into moisture, mold and dust mite problems.
2. Ensuring that basements and crawl spaces stay dry will go a long way to solving many of the observed moisture problems and subsequent biological pollution.
3. Everything that can be done to improve window condensation performance will help reduce this component of mold growth. Mold was found on window components in a majority of houses, even the ones with otherwise little mold growth.
4. The mere presence of a wood burning appliance in these houses was a good predictor of mold growth and some measures of the index child's health. We need to know more about this relationship. Is it due to the storage and handling of wood, to the biological material brought inside on wood, to larger room-to-room temperature differences, or is it simply a surrogate for some other factor that really causes the problem?
5. While good ventilation is important and helps minimize the effect of small sources of pollutants, including excessive moisture generation by occupants, ventilation by itself is not the solution to serious problems. Preventing large source strengths of any pollutant, including moisture, is necessary for problem prevention. Houses cannot be healthy if they contain large pollutant sources.
6. To be effective, ventilation must get to bedrooms, so that pollutants generated by the occupants are carried away before they reach excessive levels. If CO_2 was as high as measured in some of these houses, what were the levels of other contaminants?
7. Water tightness should be persued as vigorously as air tightness, in both new and existing houses.

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Moldy Houses: Why They Are and Why We Care, November 3, 1995

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Housing Research at CMHC

Under Part IX of the *National Housing Act*, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research.

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